BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 08048

SUBJECT: S-II Engine Actuator Forces During SA-508 POGO - Case 320

DATE: August 24, 1970

FROM: L. A. Ferrara
J. J. O'Connor

ABSTRACT

The concept that the eight gimbal servoactuators on the four outboard engines of the S-II stage can be used as strain gauges to help interpret the POGO loads on the thrust cone is developed herein.

This is the case because the (15 Hertz) POGO signals do not propogate through the autopilot, do not generate actuator commands and do not result in actuator displacements, i.e., engine gimballing. But they do create pressure differentials across the actuator piston which can be related to the forces applied at the actuator attach points, one of which is on the thrust cone and the other on the engine bell. Since a voltage is produced which is proportional to the forces applied between two points, this effectively produces a strain gauge.

The expanded traces of these differential pressure measurements show that the 14.7 Hz POGO signal is in phase on all eight actuators and is synchronous with the center engine longitudinal vibration. Such signals indicate radial forces which result in no pitch, yaw or roll moments on the vehicle.

Two traces, engine 2 and 3 pitch, show significant distortion of the sinusoidal waveform for the several cycles just prior to shutdown of the center engine. Such signals could be due to bad data and several types of instrumentation failures are considered. But they do not explain the particular features of the distortion. The alternative that these distorted data truly represent structural response during the period of maximum POGO amplitude leads to suggestions of non-linear and non-circular deformation of the thrust cone which is difficult to understand.

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MEMORANDUM FOR FILE

INTRODUCTION

During POGO on SA-508 (Apollo 13) the S-II center engine experienced ±34 g's longitudinal acceleration. There has been considerable interest in the response of the thrust cone and center engine beam to this load as it was nearly equal to the ultimate capability of the structure. For a possible insight into the structures response, we obtained an oscillographic recording of the outboard engines pitch and yaw actuator differential pressures.

These differential pressure transducers are mounted in the hydraulic circuit of the servoactuators which position each outboard engine in pitch and yaw about its gimbal block; they measure the differential pressure across the servo-actuator piston. One end of the actuator is fixed to the S-II thrust cone, the other end is attached to the engine bell, as seen on Figure 1. Each outboard engine can be gimballed ±6 degrees by the forces caused by the hydraulic pressure. If an electrical signal from the autopilot would command a change of hydraulic pressure, a servo loop with mechanical feedback would null out the pressure change as soon as the actuator achieved the desired pitch or yaw angle.

DESCRIPTION OF FLIGHT DATA

Data from previous flights, such as that contained in the S-II-3 postflight report, show that the (15 Hertz) POGO signals do not propogate through the autopilot, do not generate actuator commands and do not result in actuator displacements, i.e., engine gimballing. However, differential deflections at the actuator attach points do apply forces to the actuator. To the extent that these forces would tend to cause actuator displacements, such displacements would be sensed by the mechanical feedback cam. Since there is no electrical input command for such a displacement, the feedback loop will generate a differential pressure across the actuator piston to oppose actuator displacement. This is a feature of the servo loop to eliminate the effects of load variations. Thus the differential pressure measurements (in the absence of electrical commands) effectively make each actuator a strain gauge between its attach points.

A segment of the actuator pressure recordings just prior to center engine cutoff (CECO) has been reproduced in Figure 2. Full scale pressure values are shown at the right side of each trace. These measurements were telemetered on a channel with a sampling rate of 120 times per second and an amplitude granularity of 0.1 percent full scale. Therefore the signal is accurately measured at the instant that it is sampled, and the staircase appearance of the trace is due to the "holding" of this value until a new sample is available.

Figure 2 shows that the hydraulic forces on the actuators of all engines are in phase with each other and this is indicative of simultaneous radial "motion" of all the engines at a 14.7 Hertz rate. (See Figure 3 for engine orientation.) Such radial "motion", of course, does not result in any net pitch, yaw or roll moments on the vehicle. Comparison with the center engine longitudinal vibration oscillogram (not included herein) shows that the outboard engine actuator pressure forces are synchronous with the center engine longitudinal oscillations during the time interval displayed on Figure 2.

In order to examine the possibility of actuator displacement under the severe conditions of SA-508, we obtained the servoactuator elongation measurements (not included herein). Even with high amplification of the oscillographic recorder, there was no movement which could be correlated to the ≈15 Hertz longitudinal oscillation as seen in the servoactuator differential pressure recording.

OBSERVATIONS

The general character of the measurements of Figure 2 is that all the actuator pressures are equally and linearly responding to the POGO vibrations of the structure. This would indicate that the structural response has circular symmetry. Since the pressure measurements can be related to the forces and/or deflections at the actuator attach points, these data might be useful in the structural analysis of the thrust cone response of the POGO forcing function.

Besides these general characteristics there are several specific and disturbing features in the data of Figure 2. During the period of maximum POGO amplitude (just prior to CECO) the engine 2 and 3 pitch actuators show significant distortion of the sinusoidal waveform, and they show large negative amplitudes which are approximately 80 percent of full scale. The question is are these features due to the instrumentation system or do they represent structural response.

Three possible instrumentation system anomalies are: a bouncing wiper arm on the potentiometer from which the pressure transducer voltage is derived, a bad spot on the potentiometer and a telemetry channel problem.

A wiper arm bounce would produce zero volts (equivalent to -4000 psid, with +5 volts equivalent to +4000 psid). But Figure 2 shows that the signal did not bottom out.

The repeated negative value on the engine 3 pitch waveform would suggest a potentiometer bad spot. But the negative values for the engine 2 pitch waveform are different for each cycle.

The presence of the distortion on more than one waveform (even engine 2 yaw waveform shows some evidence of the same distortion) makes it difficult to attribute the cause to individual transducers. And the time coincidence of the distortion suggests a telemetry channel problem. But this is denied by the absence of the distortion on the other waveforms, all of which were on the same telemetry link.

Therefore we are left with the possibility that the differential pressure had a distorted time history and the measurements do indeed correctly reflect this history. It should be noted that the 15 Hertz POGO signal is probably pushing the bandwidth limitation of the transducer. Therefore, it is even more problematic to accept the indicated pressure change within the sampling interval, viz. 1/120th of a second!

Proceeding to the alternative (accepting the distortion as truly due to the structures response) raises a new series of questions. Such a distorted response would indicate a localized, non-linear structural deformation, that is, a non-circular response of the thrust cone. Figure 3 shows that the actuators with the most distortion, 2-P and 3-P, are parallel to each other, but the figure is not drawn to scale. The attach points are very close to the engine gimbal points. This raises the question as to why the waveforms of the pitch actuators of two different engines are more alike, than those of the pitch and yaw actuators of one engine. Could it be some major deformation of the thrust cone between the 2-P and 3-P attach points?

One known dissymmetry is the way the center engine loads are applied to the center engine cross-beam. The J-2 engine used in the center location is interchangeable with those used at the outboard locations, that is, it has a gimbal and two gimbal actuator attach points. Since the S-II flight control scheme does not use gimballing of the center engine, fixed-length rods are connected between the engine attach points and attach points on the cross-beam. These attach points are on the beams that go towards the engine 1 and 2 locations. It is difficult to relate this loading dissymmetry towards engines 1 and 2 to a response dissymmetry of engines 2 and 3!

It should be noted that Figure 2 shows a smooth decay of these acutator pressures after CECO. Also the engine 3 yaw actuator showed a POGO response early in the S-II burn (not shown in Figure 2) while the other actuators were comparatively quiet.

<u>SUMMARY</u>

(1) The S-II outboard engines registered forces which would tend to move them radially in synchronization with the center engine longitudinal motion during POGO.

(2) Only engine 3 yaw actuator forces were observed early in the flight.

(3) The differential pressure transducers of all eight actuators showed large amplitudes during the POGO period, but no corresponding piston motion could be detected during this time period.

(4) The engine 2 and 3 pitch pressure measurements show high-amplitude, distorted sinusoidal signals which cannot be simply discharged as bad data nor easily accepted as structural response.

L. A. Ferrara

J. J. O'Connor

2034-LAF
2031-JJO-ajj

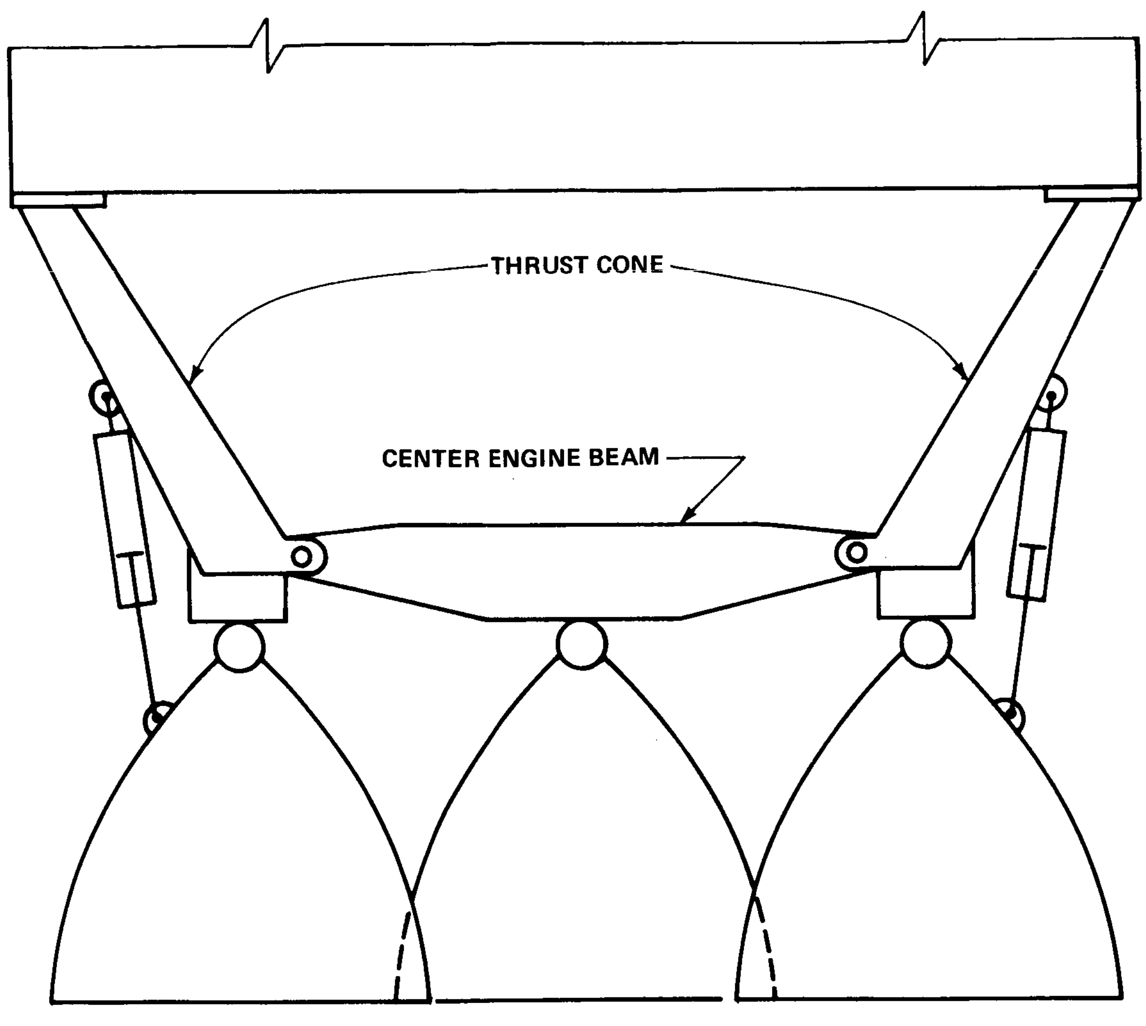


FIGURE 1 - SIMPLIFIED DIAGRAM OF S-II OUTBOARD ENGINE SERVOACTUATORS

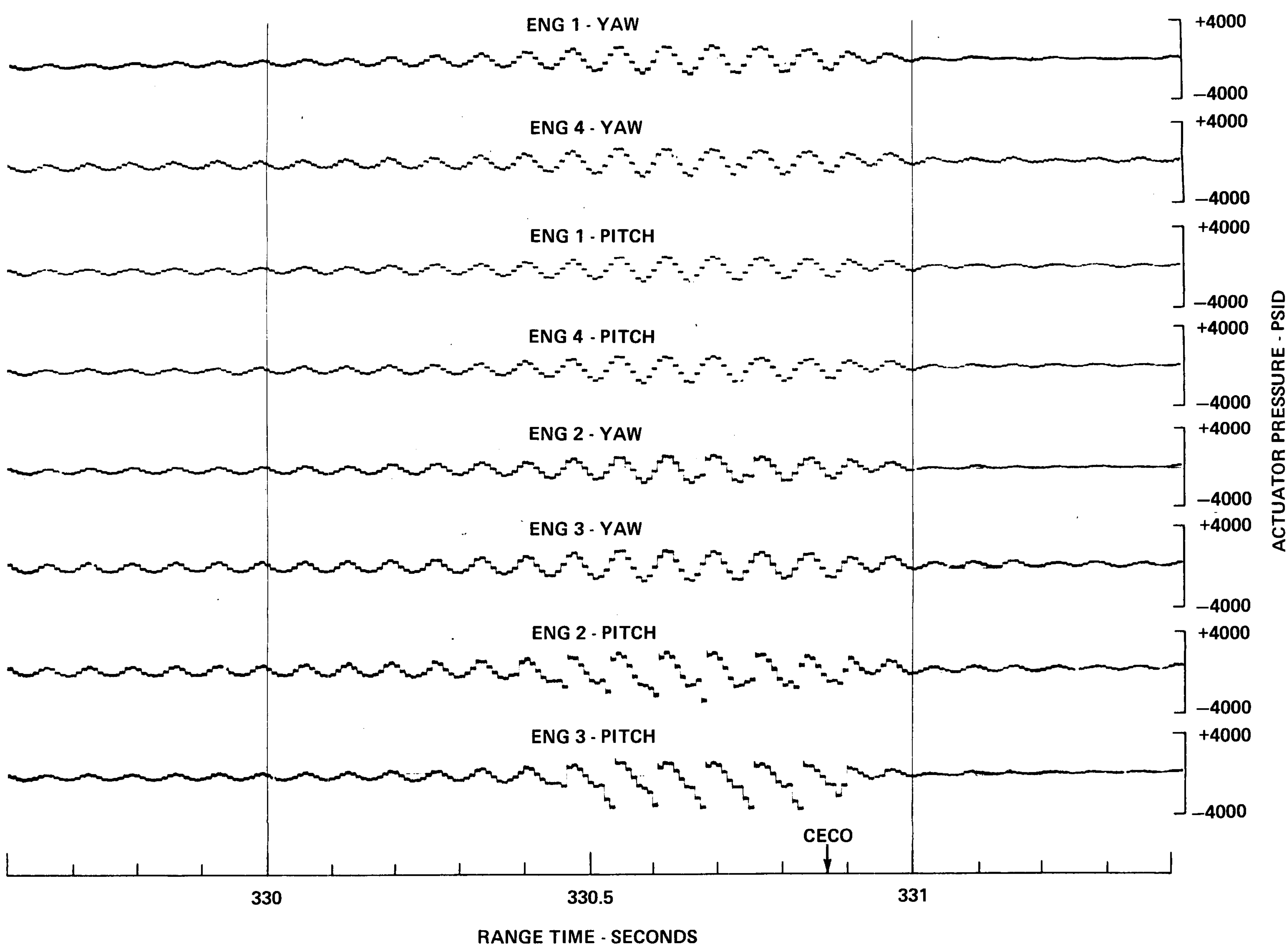
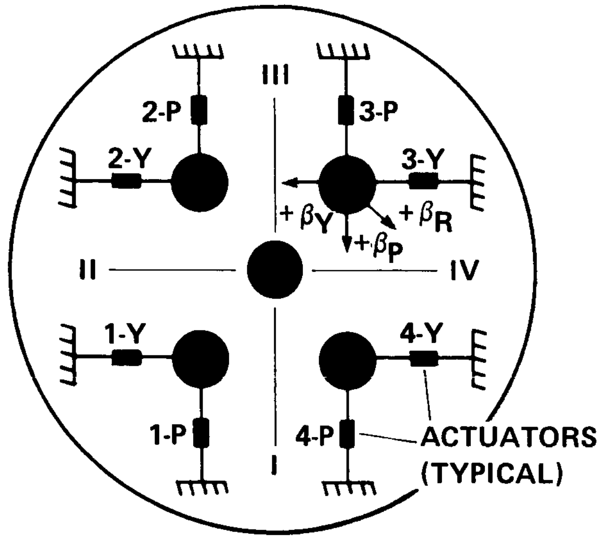
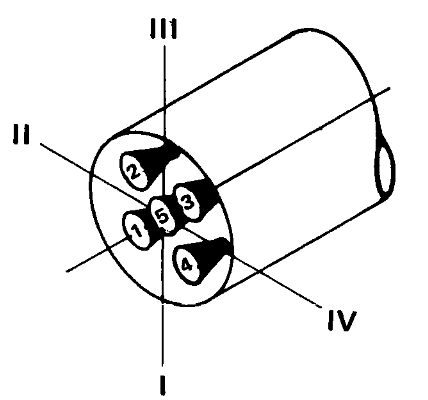


FIGURE 2 - SA-508 S-11 ENGINE ACTUATOR DIFFERENTIAL PRESSURE MEASUREMENTS



S-II ACTUATOR LAYOUT



S-II POLARITY TABLE			
ACTUATOR NO.	SIGNAL & ACTION		
	$+\psi_R$	$+\psi_Y$	$+\psi_P$
1-Y	RET	RET	
1-P	EXT		RET
2-Y	EXT	RET	
2-P	RET		EXT
3-Y	RET	EXT	
3-P	EXT		EXT
4-Y	EXT	EXT	
4-P	RET		RET

FIGURE 3 - S-II ENGINE ACTUATOR ORIENTATION